

## Methodology for Estimating Customer's Value of Increased reliability in Grid West:

To estimate the short and long benefits from increased reliability of the transmission system, this report starts with establishing the framework for calculating **Customers** cost of power interruption events. Three mutually exclusive interruptions events are recognized:

1. Momentary events (less than 5 minutes in duration measured)
2. Sustained events (greater than 5 minutes measured in the single utility footprint)
3. Cascading region wide prolong outages (one in 15-20 year events covering large areas)

Two caveats about this analysis:

- 1- This study does not attempt to capture any cost or benefit related to power quality.
- 2- Although the LBL approach described below includes both Momentary and Sustained outages, due to the data availability on Momentary outages, we did not include these type of outage in our estimation.

The analysis measures value of increased reliability in two footprints.

- 1- Four Consolidated Control Area which includes (BPA, Idaho and Pac East and Pac West)
- 2- Ten Consolidated Control Area which includes (BPA, ID, PACW, PACE, Sierra Nevada, PGE, Pudget, NWEnergy, Avista and BC )

### Cost of Momentary and Sustained events

To calculate customer cost for Momentary and Sustained interruptions we draw heavily from a new study called: “Understanding the cost of Power Interruptions to U.S. Electricity Consumers- September 2004 by Kristina Hamachi LaCommare and Joseph Eto of Lawrence Berkeley National Laboratory prepared for U.S. Department of Energy. This study was tasked with developing a comprehensive framework for assessing the cost to US electricity customers of power interruptions and power-quality problems. Details on LBL study is provided in the appendix.

The analytical framework expresses the aggregate cost of power interruption as a function of:

1. Number of customers and establishments by type
2. Frequency and Duration of interruptions annually
3. Cost of reliability events per customer per event

The tables below show the input data for our analysis.

#### Measurement for Number of Customers:

Region	Residential	Commercial	Industrial	Total
Mountain	7,368,280	1,001,310	212,842	8,582,432
Pacific	3,922,426	494,778	66,699	4,483,903
California	11,841,144	1,559,258	154,261	13,554,663
U.S.	114,317,707	14,939,895	1,582,573	130,840,175

To measure frequency and duration of sustained and momentary outages following indices are used:

- 1- System Average Interruption Duration Index- SAIDI expressed in minutes of outage per event
- 2- System Average Interruption Frequency Index- SAIFI expresses frequency of outage events per year
- 3- Momentary Average Interruption Frequency index- MAIFI expresses frequency of outage event per year

A more complete definition and measurement of SAIDI, SAIFI and MAIFI are presented in the appendix. Table below shows these values for the western region and United States.

### Regional Variation in Collected Reliability Event Data

In Minutes	SAIDI	SAIFI	MAIFI
Mountain	92	1.1	3.5
Pacific	105	1.2	3.2
California	138	1.3	2.3
U.S.	106	1.2	4.3

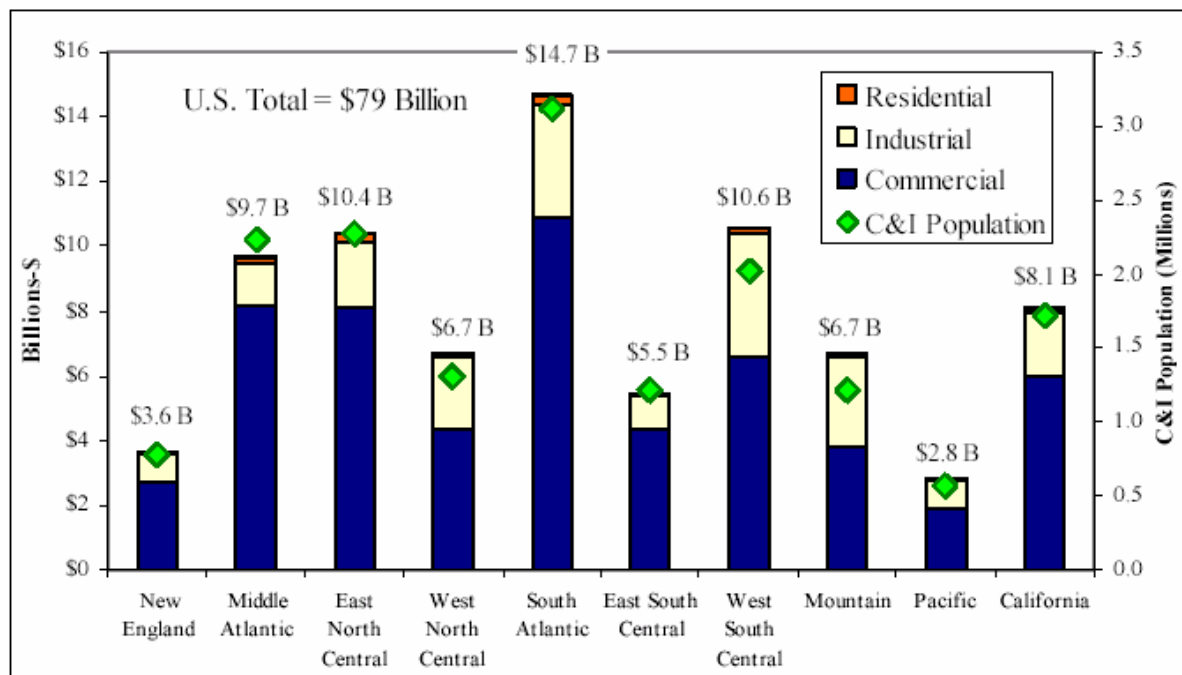
### Cost of Momentary and Sustained Outages per event per Customer

	Momentary Outages			Sustained Outages		
	Residential	Commercial	Industrial	Residential	Commercial	Industrial
Mountain	\$3.00	\$583	\$1,875	\$4.01	\$981	\$3,928
Pacific	\$1.80	\$604	\$1,881	\$2.45	\$1,050	\$4,111
California	\$1.55	\$604	\$1,881	\$2.21	\$1,050	\$4,111
US	\$2.18	\$605	\$1,893	\$2.99	\$1,067	\$4,227

Costs shown in 2002 CPI-weighted dollars

### LBNL Base-Case Estimate of the Economic Cost of Power Interruptions

LBL study finds that, based on publicly available data and subject to the limitations discussed the paper the economic cost of power interruptions to U.S. electricity consumers is \$79 billion annually.



Note: Costs are shown in U.S. 2002-CPI-weighted dollars

**Figure 9. LBNL Base-Case Estimate of the Cost of Power Interruptions by Region and Customer Class with C&I Population**

Nationally, the commercial sector accounts for more than 70 percent (\$57 billion) of the \$79 billion estimated combined total cost of power interruptions for all sectors. The commercial sector's large share of these costs is a result of the high costs per outage per customer and the large population of commercial customers. The industrial sector represents nearly 26 percent of the total cost, and the residential sector accounts for less than 2 percent of the total.

Costs tend to be driven by the frequency rather than the duration of reliability events. LBL study showed that more frequent momentary power interruptions have a stronger impact on the total cost of interruptions than less frequent sustained interruptions, which last 5 minutes or more.

Figure 9 above shows that annual cost for momentary and sustained interruptions in the Pacific, Mountain and California is about 18 billion dollars.

#### **Applying LBL study to 4 CCA and 10 CCA footprints**

Given the level of detail and the limitations of the LBL study we took the following approach in estimating the value of increased reliability resulting from GRID West operations:

- 1- Took the estimated cost of outage for California, Mountain and Pacific regions
- 2- Assumed 10% interruptions are at the transmission level and impacted by GW operations.
- 3- Estimate a range of target saving levels from improved reliability

### LBL Estimated Cost of Outages (in billions of 2002 dollars)

	Residential	Commercial	Industrial	Total
Mountain	0.1	4.8	1.80	6.70
Pacific	0.1	1.8	0.90	2.80
California	0.2	5.8	2.10	8.10
Total	0.40	12.40	4.80	17.60

### Cost of Power Interruption attributed to Transmission 10% of total (Billion dollars)

	Residential	Commercial	Industrial	Total
Mountain	0.01	0.48	0.18	0.67
Pacific	0.01	0.18	0.09	0.28
California	0.02	0.58	0.21	0.81
Total	0.04	1.24	0.48	1.76

### Cost of interruptions in CCA footprint

To estimate cost of interruptions CCA footprint we started by calculating cost of interruptions per kWh electricity consumption by sector. Using estimates for 2001 total energy consumption for the three regions, shown below we estimated cost of interruptions for BPA, PAC and ID.

2001 Sales by region ( GWH)				
	Residential	Commercial	Industrial	Total
Mountain	64,953	63,866	46,064	174,883
Pacific	56,812	47,452	48,273	152,538
California	76,843	93,627	45,483	215,952
Total	198,608	204,944	139,820	543,373
Source: EIA sales and revenue for electric utilities				

Customers Cost of Interruptions per KWH sales (mills/kWh)*			
	Residential	Commercial	Industrial
Mountain	2	75	39
Pacific	2	38	19
California	3	62	46
US Average	1.3	52	21

Note that given sector level retail rates, the cost of interruptions per kWh seems high.

Electricity Sales by sector (GWH)				
	Residential	Commercial	Industrial	Total
BPA	34,488	23,280	28,453	86,221
IDP	4,427	3,511	5,042	12,980
PAC	14,110	14,932	19,262	48,304
Total	53,025	41,723	52,757	147,505

Based on data for 2003 RDI PowerDat). BPA sales allocated 40% residential, 27% commercial and 33% industrial.

Cost of Interruptions in the 4 CCA footprint ( Million of Dollars)				
	Residential	Commercial	Industrial	Total
BPA	61	883	530	1,474
IDP	7	264	197	468
PAC	25	566	359	950
Total	92	1,713	1,087	2,892

Cost of Interruptions attributable to Transmission outages( Millions \$) in 4 CC footprint				
	Residential	Commercial	Industrial	Total
BPA	6	88	53	147
IDP	1	26	20	47
PAC	2	57	36	95
Total	9	171	109	289

### Estimating Customer's cost of Interruptions in the 10 CCA footprint

To estimate customer's cost of interruptions in the 10 CCA footprint we used the sector level electricity consumption for the remaining control areas (shown below) and multiplied it by cost per kWh from earlier table.

Control Area Name	Residential	Commercial	Industrial Sales	Total
Avista Utilities	3,817	3,285	2,608	9,709
NorthWestern Energy	2,867	3,104	532	6,503
Portland General Electric Co.	7,169	7,155	4,245	18,569
Puget Sound Energy, Inc.	9,996	8,387	1,406	19,789
BC	16,594	14,210	19,575	50,379
Sierra Pacific Power Co.	2,425	3,265	4,374	10,064
Nevada Power Co.	8,275	5,139	7,379	20,792
Total	51,142	44,544	40,119	135,806

Source: RDI database retail sales and revenue for electric utilities. BC data from Energy2020

CCA	Residential	Commercial	Industrial	Total
Avista Utilities	1	12	5	18
NorthWestern Energy	1	12	1	13
Portland General Electric Co.	1	27	8	36
Puget Sound Energy, Inc.	2	32	3	36
BC	3	54	36	93
Sierra Pacific Power Co.	0	25	17	42
Nevada Power Co.	1	39	29	69
Subtotal for the 6 CCA	9	200	99	308
<b>4 CCA</b>	<b>9</b>	<b>171</b>	<b>109</b>	<b>289</b>
<b>10 CCA</b>	<b>18</b>	<b>372</b>	<b>207</b>	<b>597</b>

## **Improvement in system reliability**

How can Grid West reduce frequency and duration of outages in its footprint?

As part of its major outage reporting WECC requires that cause of the outage be determined and corrective actions be taken. In order to better understand the cause of past outages we reviewed 31 out of 36 major outages reported to WECC. 76 separate causes lead to these 31 outages and 60% of the causes were in the following five areas:

1. Lack of detection of bulk power supply parameters that are outside normal operating limits and activation of protective devices to prevent or limit damage to the system.
2. Lack of ability of dispatch and control facilities to monitor and control operation of the bulk power supply system. Adequacy of communication facilities to provide information within and between control areas.
3. Lack of ability of system personnel to react properly to unanticipated circumstances which require prompt and decisive action.
4. Lack of ability to study of near term (daily, weekly, seasonal) operating conditions. Application of results to system operation.
5. Lack of comprehensive planning work utilizing appropriate planning criteria to provide a reliable bulk power supply system.

Grid West operations would reduce impact of these factors. We assumed that compared to the current level of reliability in the post Grid West world these five categories of disturbances can be mitigated to large extent, and to be conservative we assumed that transmission reliability would go up by only 20%. **A separate analysis by BPA shows that over 50% of outages can be mitigated by Grid West. However, we are using the more conservative 20% figure.**

Table in the following page shows number of times a given cause was present in these 31 events.

# Summary of Causes of Disturbances

Based on available information on 31 Disturbance Report WECC

Disturbance Category	Definition	Number of times Disturbance category was cause for the Outage*	% of total
1. Power System Facilities	The existence of sufficient physical facilities to provide a reliable bulk power supply system.	2	3%
2. Relaying Systems	<b>Detection of bulk power supply parameters that are outside normal operating limits and activation of protective devices to prevent or limit damage to the system.</b>	13	17%
3. System Monitoring, Operating, Control, and Communication Facilities	<b>Ability of dispatch and control facilities to monitor and control operation of the bulk power supply system. Adequacy of communication facilities to provide information within and between control areas.</b>	11	14%
4. Operating Personnel Performance	<b>Ability of system personnel to react properly to unanticipated circumstances which require prompt and decisive action.</b>	12	16%
5. Operational Planning	<b>Study of near term (daily, weekly, seasonal) operating conditions. Application of results to system operation.</b>	9	12%
6. System Reserve and Generation Response	Ability of generation or load management equipment to maintain or restore system frequency and tie line flows to acceptable levels following system disturbance.	6	8%
7. Preventive Maintenance	A program of routine inspections and tests to detect and correct potential equipment failures.	2	3%
8. Load Relief	The intentional disconnection of customer load in a planned and systematic manner to restore the balance between available power supply and demand.	2	3%
9. Restoration	Orderly and effective procedures to quickly reestablish customer service and return the bulk power supply system to a reliable condition.	1	1%
10. Remedial Action Schemes	Use of relays to initiate controlled separation and generator tripping to prevent a widespread blackout.	2	3%
11. System Planning	<b>Comprehensive planning work utilizing appropriate planning criteria to provide a reliable bulk power supply system.</b>	3	4%
Categories Number 12, 13, and 14		13	17%
	Total for the 31 cases evaluated	76	100%

- each event can have multiple causes

### Sensitivity analysis for the Cost of Interruptions

The key uncertainties in estimating customers cost of outages include:

- 1- Customer class definition – variations in commercial or industrial, small commercial and industrial or large commercial and industrial. According to LBL study anecdotal evidence suggest large customers experience higher level of reliability compared to smaller customers
- 2- Variations in SAIDI and SAIFI and MAIFI across customer class. These factors vary year by year and sector by sector. And their impact is different depending on when the outage occurs.

LBL ran a number of sensitivity studies on these key parameters found that even though the average estimated outage cost is \$79 billion dollars, cost of interruptions can be as high as \$135 billion dollars or as low as \$22 billion dollars ( plus or minus one standard deviation of the key variables). This means that on a national level costs can be 70 percent higher or 70% lower than average cost.

We applied this percentages change (+/- 70%) to our estimates for the momentary and sustained outages. Depending on the footprint for GRID West customer benefits can be as low as \$5 million for a modest decrease in frequency and duration of outage, or as high as \$508 for a 50% decrease in frequency and duration of outages. Table below shows range of benefits in the two footprints.

Based on Transmission contribution to total losses of 10 Percent						
Mitigation %	10 CCA Footprint in Millions			4 CCA footprint (BPA, ID, PAC) in \$ Million		
	Low -70%	Base	High 70%	Low -70%	Base	High 70%
5%	9	30	51	4	14	25
10%	18	60	102	9	29	49
20%	<b>36</b>	<b>119</b>	<b>203</b>	<b>17</b>	<b>58</b>	<b>98</b>
30%	54	179	305	26	87	148
40%	72	239	406	35	116	197
50%	<b>90</b>	<b>299</b>	<b>508</b>	<b>43</b>	<b>145</b>	<b>246</b>
60%	107	358	609	52	174	295
70%	125	418	711	61	202	344
80%	143	478	812	69	231	393
90%	161	537	914	78	260	443
100%	179	597	1,015	87	289	492

### **Benchmarking the Outage cost to the Gross Regional Product**

- Gross Domestic Product for 2003 is stated to be \$11,004 billion dollars.
- Total estimated cost of outages was 79 billion dollars annually
- Cost of outages as percent of GSP is 0.7%
  
- GSP for WECC excluding BC and Alberta is about 1830 billion dollars.
- Cost of outage calculated by LBL for NW, Mountain and California is 17.6 billion dollars or is about 0.1 percent of GSP produced in WECC. This percentage is consistent with the national percent.

### **BPA's Analysis**

BPA has conducted a preliminary assessment of the opportunities for improvement in system reliability. Looking at 12 years of historic information on major outages BPA staff estimated that overall a 52% potential percent mitigation is possible. For the cases evaluated route cause was identified and then evaluation was made as to whether or not GRID West operations could have mitigated the outage. Table below shows the summary of findings for the cases evaluated.

<b>Summary Table</b>	<b>Amount (Rounded)</b>
<b>Period of Analysis (years)</b>	<b>12</b>
<b>Total Causational Factors Identified</b>	<b>62</b>
<b>Causation Factors With Potential for RTO West Mitigation</b>	<b>32</b>
<b>Potential Percentage Mitigation</b>	<b>52%</b>

## **Appendix –**

- **Definitions**
- **Outages Caused by Transmission**
- **Summary of the LBL study**

**Definitions:*****SAIDI***

SAIDI (sustained average interruption duration index) is an industry-defined term to define the average duration summed for all sustained outages a customer experiences in a given time-frame. It is calculated by summing all customer minutes lost for sustained outages (those exceeding 5 minutes) and dividing by all customers served within the study area.

***SAIFI***

SAIFI (sustained average interruption frequency index) is an industry-defined term that attempts to identify the frequency of all sustained outages that the average customer experiences during a given time-frame. It is calculated by summing all customer interruptions for sustained outages (those exceeding 5 minutes in duration) and dividing by all customers served within the study area.

***MAIFI***

MAIFI (momentary average interruption frequency index) is an industry-defined term that attempts to identify the frequency of all momentary outages that a customer will experience during a given time-frame. It is calculated by summing all customer interruptions for momentary outages (those less than 5 minutes duration) and dividing by all customers served within the study area.

## Outages Caused by Transmission:

To calculate the contribution of the transmission related outages to total outage we need to compare total hours of customer outage from transmission caused outage to total number of hours of customer outage from all causes of outage. We were did not have good information on the MAIDI so our analysis looked at SAIDI alone.

$(\text{Transmission SAIDI} * \text{total number of customers}) / (\text{All-Causes SAIDI} * \text{total number of customers})$

Comparison of SAIDI figures (one for Generation &Transmission &Distribution combined and one for Transmission only) give us the contribution of transmission related outages. Using this approach we estimated that for PG&E that contribution of customer losses as a result of transmission outages is about 10% of the customer losses for all causes.

### Based on PG&E's Annual Electric Distribution Reliability report (R.96-11-004) Submitted for 2004

	TRANS. Caused SAIDI	G&T&D Total SAIDI	Ratio of transmission caused SAIDI to Total SAIDI
2000	15	168	9%
2001	19	212	9%
2002	10	140	7%
2003	19	192	10%
2004	22	196	11%

We also compared the customer losses caused by transmission outages for PacifiCorp and found that in the past 3 years between 17-12 percent of customer outages were traceable to a transmission cause.

PacifiCorp system	Transmission Caused SAIDI	Total SAIDI	Transmission related Customer Hours Lost	Total Hours of Customer Outage (all Causes) = (SAIDI * # of Customers) / 60	Transmission customer Outage as percentage of Total outage
2003	30.68	193.03	847,473	4,914,431	17%
2004	22.60	172.71	612,569	4,680,441	13%
2005	26.34	205.95	670,585	5,689,362	12%

### Idaho Power's Transmission and Total SAIDI and SAIFI

According to data provided by Mr. Ron schulberg Idaho's SAIDI for transmission is 12 minutes out of total system SAIDI of 306 minutes. In other words transmission SAIDI is about 4% of total system SAIDI.

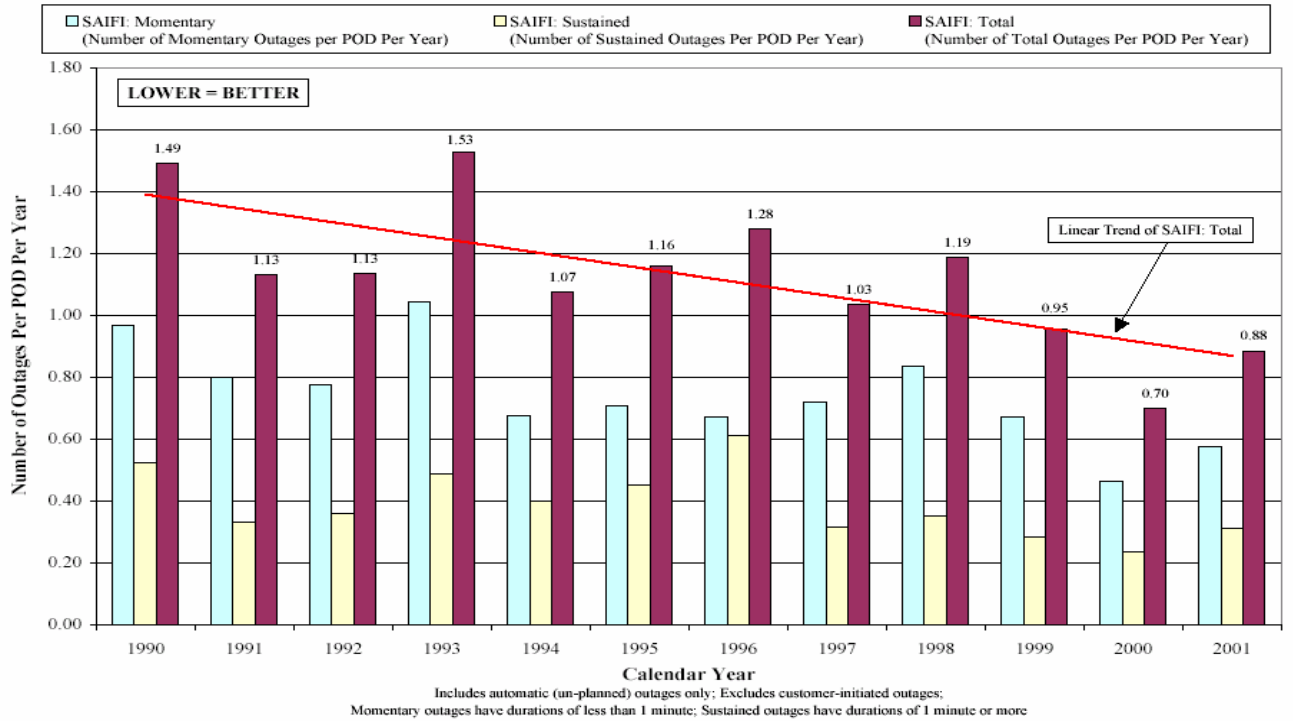
IDP	Transmission	Generation, Transmission and Distribution
SAIDI ( Minutes)	12	306
SAIFI	0.1	2.9

Table below shows BPA Customer Point-of-Delivery (POD) Reliability Performance: 1990-2001, By Year. Based on Measures of Outage Frequency (SAIFI) and Duration (SAIDI). It includes automatic (un-planned) outages only. Excludes customer-initiated outages. Momentary outages are those with duration of less than 1 minute; Sustained outages: 1 minute or more duration. Source of information is report "Reliability Impacts Associated With RTO West" by Roy Billinton, P.Eng. University of Saskatchewan based on data from BPA Transmission Business Line/Operations and Planning 25 Jan 2002.

BPA's SAIDI averages about 73 minutes given that BPA's system is primarily high voltage transmission with little distribution we could treat most of these outages as transmission outages.

Year	Number of Valid POD's	Number of Momentary POD outages	Number of Sustained Outages	Number of Total POD outages	Duration (minutes) of POD outages	SAIFI for Momentary	SAIFI for Sustained	SAIFI Total Number of Outages per POD per Year	SAIDI (Duration in Minutes of all Outages per POD per year)	Mean Distribution (minutes) of a single POD outage per Year	% of POD's with >4 outages per year	% of PODs with >150 minutes of outage duration
1990	1029	994	540	1534	64,732	0.97	0.52	1.49	62.9	42.2	11.20%	8.10%
1991	1022	818	338	1156	63,162	0.8	0.33	1.13	61.8	54.6	7.10%	4.70%
1992	1029	797	369	1166	138,258	0.77	0.36	1.13	134.4	118.6	7.40%	6.10%
1993	1031	1073	503	1576	111,198	1.04	0.49	1.53	107.9	70.6	11.50%	9.70%
1994	1030	696	411	1107	54,785	0.68	0.4	1.07	53.2	49.5	6.70%	7.20%
1995	947	667	428	1095	61,479	0.7	0.45	1.16	64.9	56.1	8.40%	8.30%
1996	918	614	561	1175	92,322	0.67	0.61	1.28	100.6	78.6	8.20%	15.10%
1997	916	658	290	948	41,651	0.72	0.32	1.03	45.5	44	5.60%	5.50%
1998	906	756	318	1074	69,896	0.83	0.35	1.19	77.1	65.1	8.50%	4.60%
1999	896	602	252	854	50,882	0.67	0.28	0.95	56.8	59.6	6.10%	4.70%
2000	891	412	210	622	68,340	0.46	0.24	0.7	76.7	109.9	2.70%	5.20%
2001	883	508	273	781	35,065	0.58	0.31	0.88	39.7	44.9	4.80%	4.80%
Ave.		716	374	1,091	70,981	0.7	0.4	1.1	73.5	66.1	7%	7%

# **BPA Customer Point-of-Delivery Reliability Performance: 1990-2001, By Year** **Measures Of Outage Frequency**



## Summary of LBL Study

**Understanding the cost of Power Interruptions to U.S. Electricity Consumers-**  
September 2004 by Kristina Hamachi LaCommare and Joseph Eto of Lawrence Berkeley  
National Laboratory prepared for U.S. Department of Energy.

This study was tasked with developing a comprehensive framework for assessing the cost to US electricity customers of power interruptions and power-quality problems.

### **An End-Use Framework for Estimating the Economic Cost of Power Interruptions and Power Quality**

This section describes an end-use framework for estimating the economic costs of power interruptions and power quality to U.S. electricity consumers. The framework relies on a simple mathematical expression that determines the economic cost of power interruptions and power quality as follows:

$$\text{Cost of Power Interruptions and Power Quality} = \sum_{i=1}^m \sum_{j=1}^n \sum_{k=1}^p N_{i,j} \times F_{i,j,k} \times C_{i,j,k} \times V_{i,j,k}$$

where,

$N$  = number of electricity customers, by customer class for each region

$F$  = the frequency of reliability events by type of event experienced annually by customers by customer class for each region

$C$  = the cost per event by type of reliability event per customer by customer class for each region (2002-CPI-weighted dollars/event)

$V$  = the vulnerability of customers to each type of reliability event by customer class for each region (a fraction between 0 and 1)

$m$  = the number of customers in each customer class

$n$  = the number of regions

$p$  = the type of reliability event

$i,j,k$  = indices for customer class, region, and type of reliability event, respectively

Sources of data used for the study is presented in the table 3.

**Table 3. The Data Used to Develop a National Estimate of the Cost of Power Interruptions**

Customers	Customer classes (residential, commercial, and industrial) and populations are defined and estimated using data from the U.S. Energy Information Administration for 10 regions of the U.S. (with separate treatment for California.)
Duration and Frequency of Reliability Events	Trimmed means for SAIDI, SAIFI, and MAIFI data collected through an on-line search (N = 162, 162, and 52, respectively.) <sup>13</sup>  Within each region, all customers are assumed to experience the same duration and frequency of reliability events because current reporting of SAIDI, SAIFI, and MAIFI does not distinguish between customer classes.  Information on power quality events is not included.
Cost of Reliability Events	Customer damage functions for three customer revenue classes (residential, small and medium C&I, and large C&I) are taken from a recent national study of utility outage cost surveys conducted by Population Research Systems and LBNL (Lawton et al. 2003). In total, over 60,000 survey responses from 24 past utility studies were combined to support the estimation of customer damage functions.  Customer damage functions express the cost of an outage as a function of outage duration, season, time of day, annual electricity use, and depending on the customer class, household income or number of employees.

N: The customer population data were taken from EIA's *Electric Sales and Revenue* publication (Energy Information Administration 2003b). The data are reported for year 2001 by state and by demand sector (residential, commercial, and industrial).

F: Duration and frequency of reliability Events (SAIDI, SAIFI and MAIFI):

The System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) describe the duration and frequency, respectively, of *sustained* interruptions experienced by customers of a utility in one year (IEEE 1995; IEEE 1999). According to IEEE, a "sustained interruption" is defined as any interruption that lasts at least five minutes and is not classified as a momentary interruption. The SAIDI index represents the average length of time customers are interrupted and is defined as,

$$\text{SAIDI} = \frac{\text{Sum of customer (sustained) interruption durations for all customers}}{\text{Total number of customers served}}$$

The SAIFI index represents the total number of customer interruptions per customer for a specified electric supply system and is defined as,

$$\text{SAIFI} = \frac{\text{Total number of customer (sustained) interruptions for all customers}}{\text{Total number of customers served}}$$

The MAIFI index is a useful measure for assessing the frequency of momentary interruptions. However, the data are not as commonly collected and, therefore, more difficult to find. Consistent with IEEE's definition of a sustained interruption, a momentary outage is defined as any event lasting less than five minutes. The MAIFI index is therefore defined as,

$$\text{MAIFI} = \frac{\text{Total number of customer momentary (< 5 min) interruptions for all customers}}{\text{Total number of customers served}}$$

Table 5 shows the variation of the means and standard deviations with and without the trimming process. Here we can see that removing the highest and lowest five percent of data points in each data set has a noticeable effect on the resulting average duration of outages. By removing the outliers, the SAIDI average decreases from 122 minutes to 106 minutes, while the SAIFI and MAIFI means change very little. More interesting is the significant reduction in the magnitude of the standard deviation with these three indices. The standard deviation for both SAIDI and SAIFI are roughly halved when ten percent of the outlying data points are removed and is reduced by more than ten percent for MAIFI. This suggests that trimming the highest and lowest five percent of data points helps to significantly improve the robustness of our means.

**Table 5. Summary of Trimmed Mean and Total Mean Reliability Event Data**

	SAIDI	SAIFI	MAIFI
Trimmed Mean	106 min.	1.2	4.3
(Standard Deviation)	(54 min.)	(0.5)	(3.6)
Total Mean	122 min.	1.3	4.6
(Standard Deviation)	(115 min.)	(1.0)	(4.1)

### The Cost of Reliability Events

The cost analysis incorporates findings from a recent study published by Population Research Systems (PRS), LLC and Lawrence Berkeley National Laboratory (Lawton et al. 2003) “PRS Study.” The PRS study is a meta-analysis of 24 independent customer surveys conducted by eight electric utility companies in the U.S. over the past 13 years. Multiple regression analysis techniques were used to combine the survey data into equations that express outage costs per customer as a function of multiple, independent parameters. The PRS study developed analytic expressions, called customer damage functions, that express customer outage costs as a function of customer class, region, event duration, and other descriptive variables based on a data set of survey responses from more than 2,000 large C&I, 5,200 small and medium C&I, and 11,000 residential customers. The cost-per-outage-per customer data were normalized and reported in year-2002 Consumer-Price-Index (CPI)-weighted dollars.

Table 7 summarizes the various independent parameters included in the cost damage functions. “Duration” is the length of outage in hours; the duration squared term is included in the Tobit regression results because outages costs are not monotonic with respect to time. The squared parameter in the equation adjusts the predicted interruption cost to reflect the declines that are typically observed after outage costs reach their maximum. “Interaction duration and kWh” is the mathematical product of duration and annual kWh consumption; this predictor is included because the effect of duration on interruption cost increases with customer usage or size.

**Table 7. Summary of Tobit Regression Parameters**

Predictor	Residential	Commercial	Industrial
Intercept	0.2503	6.48005	7.7954
Duration (hours)	0.2211	0.38489	0.5753
Duration (hours) Squared	-0.0098	-0.02248	-0.0338
Number of Employees		0.001882	0.0007
Annual kWh (MWh for Resd.) <sup>1</sup>	0.0065	0.0000017	2.52E-08
Interaction Duration and kWh <sup>1</sup>		9.46E-08	-1.8E-09
Morning	-0.0928	-0.6032	-0.5624
Night	-0.1943	-0.91339	-1.3857
Weekend	-0.0134	-0.52041	-0.7149
Winter	0.1275	0.37674	0.8992
Log of Household Income	0.0681		
Southeast	0.2015		
West	-0.1150		
Southwest	0.5256		

<sup>1</sup> 1 kWh = 1,000 watt-hours, 1 MWh = 1,000,000 watt-hours

Source: Lawton et al. 2003.

The “morning,” “night,” “weekend,” and “winter” flags can be turned “on” (set to one) to denote that an outage is occurring during the given time period or “off” (set to zero) to denote that the outage is not occurring during the given time period. These parameters are weighted based on the number of hours that each of the time periods constitute annually; these time periods are derived from permutations of these four parameters and are further explored in the sensitivity analysis.

The “log of household income” is the logarithmic transformation of household income used to correct for skewness in the household income parameter.

The “southeast,” “west,” and “southwest” parameters can also be turned on or off to identify the region for which the regression is being performed. When all three regional parameters are set to zero, the equation is solved for the north region. The regions included are those for which outage cost data were collected in the PRS meta-analysis (Lawton et al. 2003).

**Table 9. Tobit Regression Season, Time of Day, and Day Type Parameter Combinations**

	morning	night	weekend	winter	Description	Hours of the Year
1	1	0	0	0	summer, weekday, morning	756
2	0	0	0	0	summer, weekday, afternoon	756
3	0	1	0	0	summer, weekday, night	1,512
4	1	0	1	0	summer, weekend, morning	339
5	0	0	1	0	summer, weekend, afternoon	339
6	0	1	1	0	summer, weekend, night	678
7	1	0	0	1	winter, weekday, morning	756
8	0	0	0	1	winter, weekday, afternoon	756
9	0	1	0	1	winter, weekday, night	1,512
10	1	0	1	1	winter, weekend, morning	339
11	0	0	1	1	winter, weekend, afternoon	339
12	0	1	1	1	winter, weekend, night	678

**Summary of Reliability Event Costs**

Table 10 shows the costs per outage per customer used in the Tobit regression equation to calculate the total cost of power interruptions to U.S. electricity customers. The cost data are classified by customer class (residential, commercial, industrial) and outage duration for the U.S.

The costs per outage per customer for individual regions are presented later in this report as part of our sensitivity analysis. Our initial estimate uses the U.S. estimated cost per outage per customer. This table represents the costs for momentary interruptions (i.e. “0 sec”), 1-hour outages, and the length of outage calculated from our trimmed means of SAIDI and SAIFI (i.e., “Sustained Interruption”). Both the “0 sec” and “Sustained Interruption” costs are used to derive initial estimate with the 1-hour cost used later in sensitivity analysis. It is shown here to indicate the costs associated with this commonly reported outage length. The sustained interruption cost-per-outage-per-customer assumes the trimmed mean outage duration of 106 minutes presented in Section 4.2.

**Table 10. Tobit Regression Estimated Cost-per-Outage-per-Customer for the U.S.<sup>1</sup>**

Duration	Residential	Commercial	Industrial
0 sec	\$2.18	\$605	\$1,893
1 hour	\$2.70	\$886	\$3,253
Sustained Interruption	\$2.99	\$1,067	\$4,227

<sup>1</sup>Costs shown in U.S. 2002 CPI-weighted dollars

Table 13 shows the momentary and sustained per-outage per-customer costs used in this sensitivity case for each region. In general, the per-outage cost does not vary considerably across regions.

**Table 13. Tobit Regression Estimated Cost-per-Outage-per-Customer by Region<sup>1</sup>**

AVERAGE COST PER EVENT BY CUSTOMER CLASS, REGION, AND DURATION OF OUTAGE <sup>1</sup>				
Region	Duration	Residential	Commercial	Industrial
New England (1)	0 sec	\$1.75	\$602	\$1,885
	Sustained Outage	\$2.64	\$1,256	\$5,335
Middle Atlantic (2)	0 sec	\$1.76	\$676	\$1,880
	Sustained Outage	\$2.59	\$1,370	\$5,020
East North Central (3)	0 sec	\$1.77	\$567	\$1,904
	Sustained Outage	\$2.43	\$995	\$4,252
West North Central (4)	0 sec	\$1.79	\$574	\$1,901
	Sustained Outage	\$2.36	\$940	\$3,838
South Atlantic (5)	0 sec	\$2.23	\$655	\$1,901
	Sustained Outage	\$3.05	\$1,164	\$4,244
East South Central (6)	0 sec	\$2.24	\$602	\$1,923
	Sustained Outage	\$3.08	\$1,062	\$4,293
West South Central (7)	0 sec	\$1.82	\$574	\$1,895
	Sustained Outage	\$2.35	\$907	\$3,639
Mountain (8)	0 sec	\$3.00	\$583	\$1,875
	Sustained Outage	\$4.01	\$981	\$3,928
Pacific (9)	0 sec	\$1.80	\$604	\$1,881
	Sustained Outage	\$2.45	\$1,050	\$4,111
California (10)	0 sec	\$1.55	\$604	\$1,881
	Sustained Outage	\$2.21	\$1,050	\$4,111
U.S. Total	0 sec	\$2.18	\$605	\$1,893
	Sustained Outage	\$2.99	\$1,067	\$4,227

<sup>1</sup>Costs shown in U.S. 2002 CPI-weighted dollars